SOIL WATER WITHDRAWAL AND ROOT DISTRIBUTION UNDER GRUBBED, SPRAYED, AND UNDISTURBED BIG SAGEBRUSH VEGETATION

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Abstract.— Seasonal depletion by vegetation where sagebrush was selectively removed by grubbing and where sagebrush was sprayed with 2,4-D was 33 and 12 percent less, respectively, than that for undisturbed big sagebrush vegetation in the surface 122 cm of soil. Differences were located primarily below 61 cm in vegetation grubbed the previous fall and below 91 cm in vegetation sprayed three years previously. Total root weights under grubbed and sprayed vegetation were 29 and 16 percent less, respectively, than for undisturbed big sagebrush vegetation. Total herbaceous production by grubbed and sprayed vegetation was 69 and 43 percent less, respectively, than production by undisturbed vegetation.

Big sagebrush (*Artemisia tridentata*) is commonly controlled with herbicides, mechanical methods, or fire to increase livestock forage production. Phenoxy herbicides such as 2,4-D damage forbs as well as sagebrush, so that the net effect of spraying is to favor grass productivity.[2] Burning or mechanical sagebrush control techniques, however, do not selectively favor grasses. Herbaceous production commonly doubles or triples by the second or third year after sagebrush removal.

The shift from a shrub to a herbaceous-dominated vegetation produces other ecologic and hydrologic changes. This study was made to quantify differences in the soil water regime and in root biomass between undisturbed big sagebrush vegetation and (a) herbaceous vegetation three years after spraying with 2,4-D and (b) herbaceous vegetation from which only big sagebrush was removed by mechanical means the previous fall. Information about herbaceous productivity was also collected.

Literature Review

Changes in the soil water regime after sagebrush control are strongly influenced by rooting characteristics of sagebrush and herbaceous species. Roots of basin big sagebrush (*A. t.* sub. *tridentata*) and mountain big sagebrush (*A. t. vaseyana*) commonly extend about 2 m deep and have a maximum lateral spread from the trunk of 1.5 m (Goodwin 1956, Cook and Lewis 1963, Tabler 1964, Hull and Klomp 1974, Sturges and Trlica 1978). Most roots are in surface soil where maximum spread occurs. About 60 percent of total root length (Tabler 1964) and 85 percent of total root system weight were present in the surface 61 cm of soil, with only about 4 percent in soil below 91 cm (Sturges and Trlica 1978).

The principal soil water reservoir utilized by isolated mountain big sagebrush plants extended 0.9 m laterally from the trunks and 0.9 m deep (Sturges 1977b). The plants utilized water from surface soil adjacent to the trunk early in the growing season, but use-zones shifted outward and downward later in the summer as water adjacent to the trunk was depleted. Appreciable water uptake was detectable until early in August.

Tabler (1968) and Sturges (1977a) found that seasonal soil water withdrawal was reduced after spraying sagebrush vegetation

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[2]This article reports research involving pesticides. It neither contains recommendations for their use nor implies that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended. Use all pesticides selectively and carefully; read and follow the directions on the label.

with 2,4-D on sites with deep soils that were fully recharged by snowmelt. This reduction was located almost entirely below 91 cm as depletion of surface soil water by sprayed vegetation sometimes exceeded depletion by untreated vegetation. Water depletion in surface soil increased the first few years after treatment as herbaceous vegetation responded to release from sagebrush competition. Other studies also detected an increasing moisture draft from surface soil with time (Hyder and Sneva 1956, Cook and Lewis 1963, Shown et al. 1972).

Herbaceous production was measured in most soil moisture studies. Grass production doubled the year after spraying mountain big sagebrush and was 2.6 times higher than untreated vegetation three years after treatment (Sturges 1977a). Shown et al. (1972) found that usable forage production increased 300 percent compared to pretreatment conditions once a planted grass stand became established. Hyder and Sneva (1956) found the increase in grass production to be the same whether big sagebrush was controlled by spraying or by grubbing. Total herbaceous production increased the most where sagebrush was grubbed, because forbs were damaged by the spray.

Study Area

The study was performed at the Stratton Sagebrush Hydrology Study area 29 km west of Saratoga in south-central Wyoming. The experimental site is at an elevation of 2,225 m and lies on a north-facing slope in a moderate snow catchment zone. Annual precipitation is about 500 mm, with two-thirds of the total falling as snow. Precipitation between 1 June and 30 September averages 114 mm. Sufficient snow usually accumulates to completely recharge the soil mantle. Soils developed in place from sandstone and belong to the Argic Cryoboroll great soil subgroup. A dense stand of mountain big sagebrush, underlain by a productive understory of bunch grasses—primarily Idaho fescue (*Festuca idahoensis*), bluegrass (*Poa* spp.) and needlegrasses (*Stipa* spp.)—was present before study initiation. The site had been grazed by sheep, but no grazing occurred during the study.

Methods

Work began in 1968 with a study that utilized 14 0.4-ha experimental units arranged in seven blocks to determine how the soil water regime would be affected by spraying big sagebrush (Sturges 1977a). One experimental unit within each block was sprayed with 2,4-D in 1970; the other unit remained untreated. Experimental units from three of the seven blocks were used in the current study. In October 1972, smaller plots 23 m long and 10 m wide were established on either side of the common border between sprayed and unsprayed vegetation (Fig. 1). These plots were used to obtain soil cores and to create the grubbed sagebrush vegetative condition. Sagebrush was grubbed from four circular areas 6.1 m in diameter by cutting plants at or slightly below the ground surface. Grubbing was done in the fall of 1972, when vegetation was dormant, thereby minimizing damage to residual herbaceous vegetation and insuring that herbaceous vegetation would be as comparable as possible to that within the undisturbed sagebrush stand when study measurements began the following spring.

Soil Water Measurements

Soil water content was measured with a neutron-scattering soil moisture meter at four randomly located access tubes on each experimental unit. Access tubes within grubbed vegetation were installed at the center of each cleared circle in October 1972. If one assumes that big sagebrush has a maximum lateral root spread of 1.5 m, these tubes were surrounded by a volume of soil at least 1.5 m in radius devoid of live sagebrush roots.

Moisture measurements began 31 May 1973 upon completion of snowmelt and continued at biweekly intervals until 19 September 1973, when vegetation was dormant. Measurements were taken at eight depths: 15, 30, 46, 61, 76, 91, 107, and 122 cm. The manufacturer-supplied calibration curve relating field neutron count (expressed as a percentage of shield count) to volume moisture content was applied to all data except that collected at 15 cm. Here, a correction was made for escape of neutrons into the atmosphere using a polyethylene shield technique similar to Pierpoint's (1966).

Root Weights

Soil cores for sampling root weight were obtained at four random locations within the small plots that straddled the common border between sprayed and undisturbed sagebrush vegetation. The cores were collected in September following the final soil water measurement (Fig. 2). Each core was 7.6 cm in diameter and 122 cm long. The cores were collected in 15-cm increments using the device described by Brown and Thilenius (1977). Each sample site in grubbed vegetation was located within 2.4 m of an access tube, a minimum of 0.6 m from the surrounding sagebrush cover. Soil cores were placed in plastic bags and frozen on the day of collection. After thawing, core segments were individually washed in a core-washing machine (Brown and Thilenius 1976) to isolate root matter from soil. Roots were oven dried for 24 hours at 70 C and weighed on an analytical balance. It was not possible to distinguish between live and dead roots, but woody sagebrush roots from cores taken within grubbed vegetation were discarded before samples were weighed.

Herbaceous Production

Above-ground herbaceous productivity was measured by clipping 12 randomly located plots within each experimental unit as grasses matured in mid-July. In grubbed vegetation, three production plots were placed

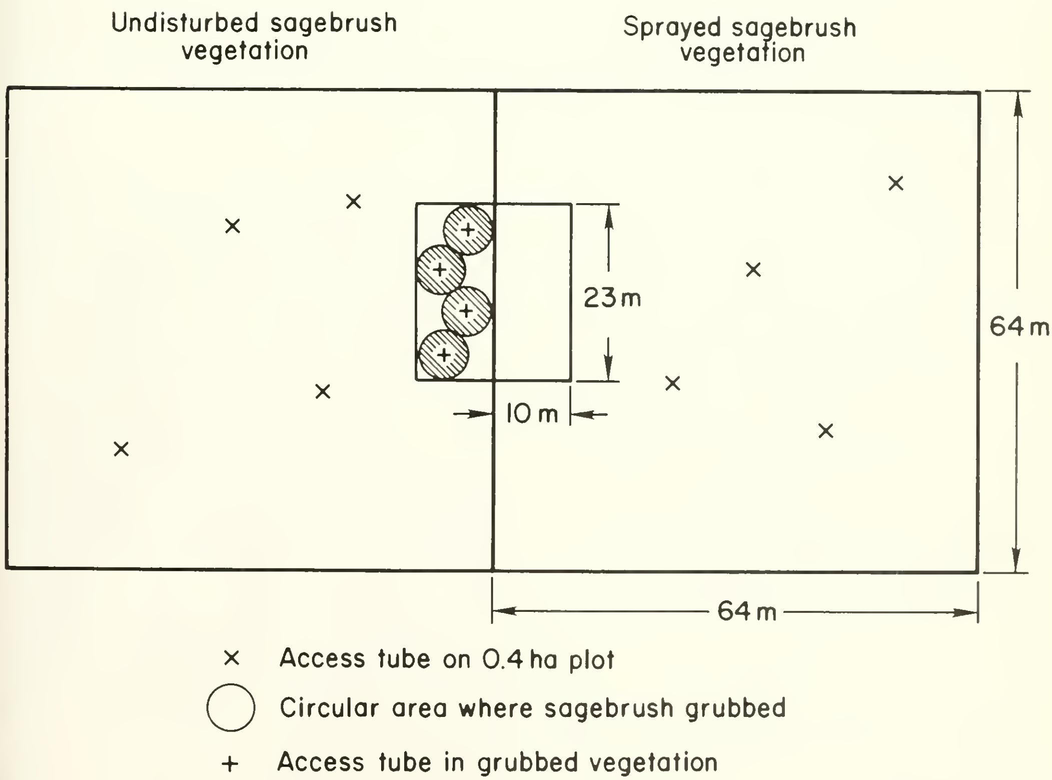

Fig. 1. The experimental design for one block showing the 0.4-ha experimental units of undisturbed and sprayed sagebrush vegetation and smaller plots where sagebrush was grubbed. Soil moisture data, soil cores, and herbaceous productivity information for the grubbed treatment were obtained on the small plot.

at random within 2.4 m of access tubes. Vegetation was harvested to a 1 cm stubble height from plots 30.5 cm wide and 61 cm long. Vegetative matter was separated into grass, forb, or sagebrush components and placed in paper bags when harvested. Only leaves and herbaceous stem material were included with sagebrush herbage. Vegetation samples were subsequently dried at 105 C for 24 hours and weighed.

Selected big sagebrush and productivity characteristics were measured in 1969 on the 0.4-ha experimental units, the year before spraying (Table 1). No statistically significant differences before treatment were present. Big sagebrush contributed 76 percent of aboveground herbaceous production while grasses contributed 20 percent and forbs 4 percent. About one-third of the area was covered by the live, leafy portion of the sagebrush canopy. Sagebrush plants had an average height of 34 cm and an average crown area of 7 dm^2.

Statistical Analysis

Soil water withdrawal and root weight differences among the three vegetative conditions were tested for statistical significance by variance analysis utilizing a split-plot design. Experimental units (whole units) were arranged in three randomized blocks, and the eight measurement depths served as subunits. Analyses were based on average plot values determined from the four replicated measurements on the plot. Variables analyzed were the change in soil water content between successive sampling dates, the seasonal change in soil water content, and root weight. Herbaceous productivity data were analyzed with a randomized block design.

Results

Soil Water Depletion

Soil under undisturbed and sprayed vegetation was completely recharged by snowmelt on the first measurement date, but only to 61 cm under grubbed vegetation (Fig. 3). At the end of summer, water content in the surface 46 cm of soil was similar for all treatments. Below 46 cm, progressively more water remained in soil under grubbed vegetation compared to undisturbed sagebrush vegetation, but appreciable differences between sprayed and undisturbed vegetation were present only below 91 cm.

Seasonal water withdrawal by undisturbed, sprayed, and grubbed vegetation was 24.3, 21.4, and 16.2 cm of water, respectively, in the surface 122 cm of soil. These differences

Table 1. Characteristics of vegetation on plots assigned to spray and undisturbed treatments in 1969, one year before 2,4-D was applied.

Sagebrush	Undisturbed	Sprayed
Height (cm)	30°	37
Canopy area (dm^2)	6	8
Canopy intercept (%)	31	32
Density (number/ha)	57,000	52,000
Herbaceous production (kg/ha)		
Sagebrush	926	1095
Grass	249	290
Forb	53	60
Total	1228	1445

°Differences between treatment means were not significant for any measurement parameter at the 0.05 level of probability.

Fig. 2. Root samples were obtained using a core sampler driven into the soil to a 122-cm depth by 15-cm increments.

were significant at the 0.01 probability level. Treatment differences did not accrue uniformly through the soil mantle, but were concentrated at deeper soil depths (Fig. 4). Between 91 and 122 cm, depletion by grubbed and sprayed vegetation was 31 and 66 percent, respectively, of depletion by undisturbed sagebrush vegetation.

Treatment soil water withdrawal differences between consecutive measurement dates were significant ($p \leq 0.05$) only between 25 June and 10 July. The treatment x depth interaction term was significant during five of the eight measurement intervals, though, indicating that the three vegetative conditions were utilizing water differently from within the soil. For example, most of the difference in depletion below 91 cm between

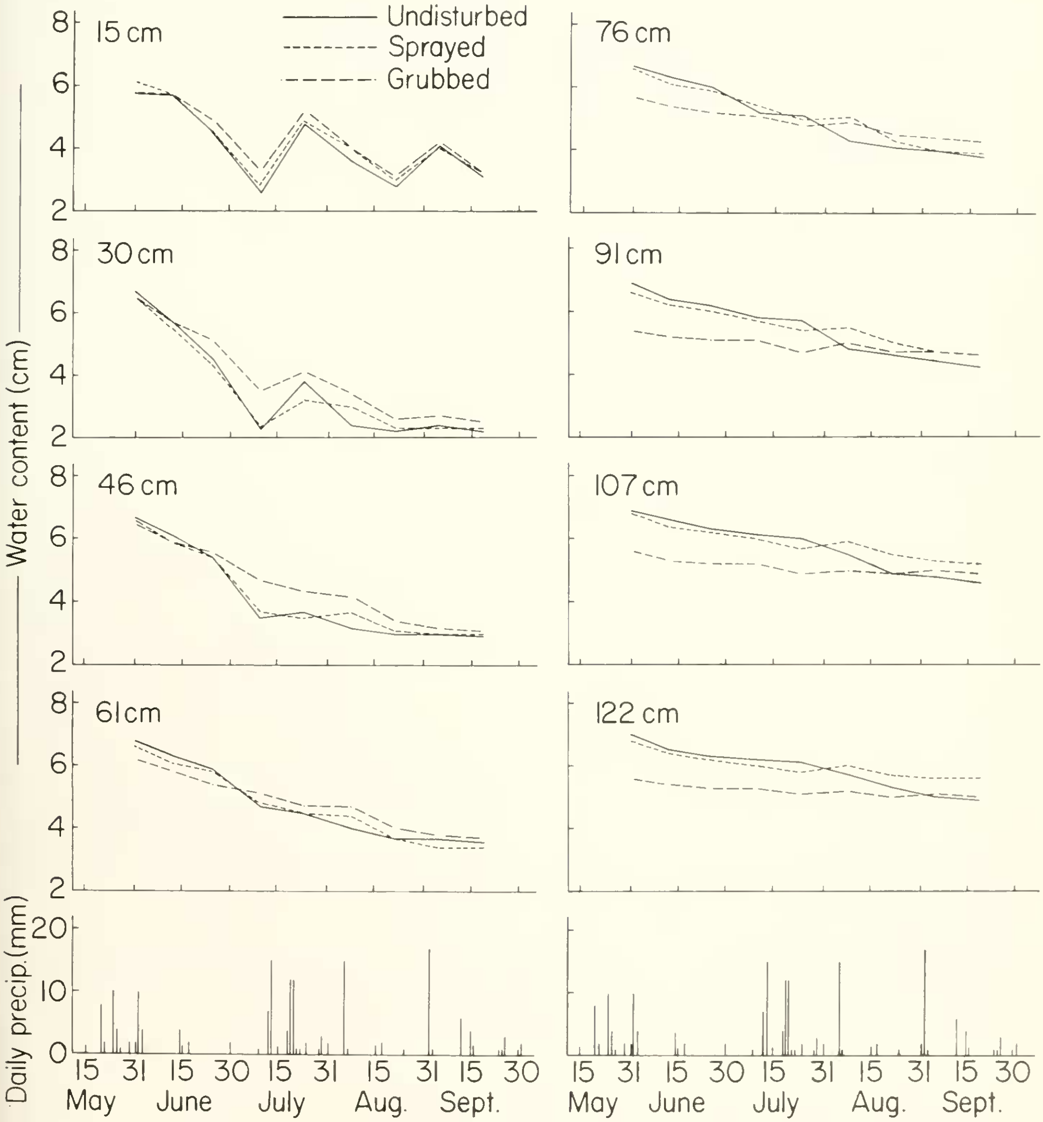

Fig. 3. Daily precipitation and soil water content in the surface 122 cm of soil for undisturbed, sprayed, and grubbed sagebrush vegetation in the 1973 growing season.

sprayed and undisturbed vegetation developed after 25 July. Sagebrush remained physiologically active through the summer and flowered about 1 September, so that appreciable water usage continued all summer. Most grass and forb species had matured and set seed by early August, thus reducing the need for water by grubbed and sprayed vegetation.

Root Weights

The average weight of roots obtained from soil cores extending 122 cm deep was 12.2, 10.2, and 8.7 g under undisturbed, sprayed, and grubbed vegetation, respectively. Neither the treatment, nor the depth x treatment interaction term was statistically significant. Varying quantities of dead but undecayed root matter and other organic debris were included with sample material and could not be separated from live roots. Inclusion of extraneous matter probably accounted, in part, for the low statistical sensitivity of root measurements.

Most of the weight of roots was located in surface soil (Fig. 4). Material from the surface 15 cm of soil ranged from 36 percent of total root weight in undisturbed sagebrush vegetation to 54 percent of total root weight in sprayed vegetation. Conversely, only 1 to 2 percent of root weight for each treatment came from the deepest sampling depth.

Herbaceous Production

Herbaceous production of undisturbed sagebrush vegetation was about a third greater in 1973 than in 1969, but composition of vegetation was similar both years. Treatment differences within sagebrush, grass, and total production herbage classes were highly significant (Table 2). The response by sprayed vegetation the third year after treatment was typical to that reported from other locations. Grass production was 2.6 times greater than production in undisturbed sagebrush vegetation, but forb production was still depressed below pretreatment levels. Total herbaceous production by sprayed vegetation was only 57 percent as large as production by undisturbed sagebrush vegetation, the increase in grass production not compensating for loss of sagebrush.

Grass production increased 27 percent where sagebrush was grubbed the previous fall, but the increase was not statistically significant (Table 2). Total production was 31 percent as high as that by undisturbed vegetation because of the loss of sagebrush.

Discussion and Conclusions

This study indicates the soil water regime in the surface 91 cm of soil is unaffected by sagebrush control once herbaceous vegetation responds to release from sagebrush competition. However, below 91 cm, substantial reductions in seasonal withdrawal can occur as reported by Tabler (1968) and Sturges (1977a). The overall reduction in soil water depletion caused by grubbing sagebrush compares closely with that detected on the same 0.4-ha experimental units in 1970 when sagebrush was sprayed. Grubbing decreased seasonal water withdrawal 33 percent in this study, and spraying reduced withdrawal from the surface 137 cm of soil 37 percent (from the spray date on 22 June through 30 September). The year after spraying, a 17 percent difference in seasonal withdrawal was observed with grass production doubling in response to sagebrush removal.

Reductions in moisture withdrawal are related to decreased aboveground herbaceous productivity of treated vegetation. Productivity in grubbed and sprayed vegetation was 31 and 57 percent as large, respectively, as that of undisturbed vegetation. Development of vegetation in years immediately following sagebrush control also influenced water withdrawal patterns. Seasonal depletion under grubbed vegetation was less than that of undisturbed sagebrush vegetation at all depths, but appreciable differences existed only be-

TABLE 2. Aboveground herbaceous production (kg/ha) by undisturbed, sprayed, and grubbed vegetation in 1973.

Treatment	Sagebrush	Grass	Forb	Total
Undisturbed	[*]1201[a]	347[a]	86[a]	1634[a]
Sprayed	1[b]	918[b]	16[b]	935[b]
Grubbed	0[b]	442[a]	67[a]	509[c]

[*]Treatment means having different letters within a column are significantly different at the 0.05 level of probability.

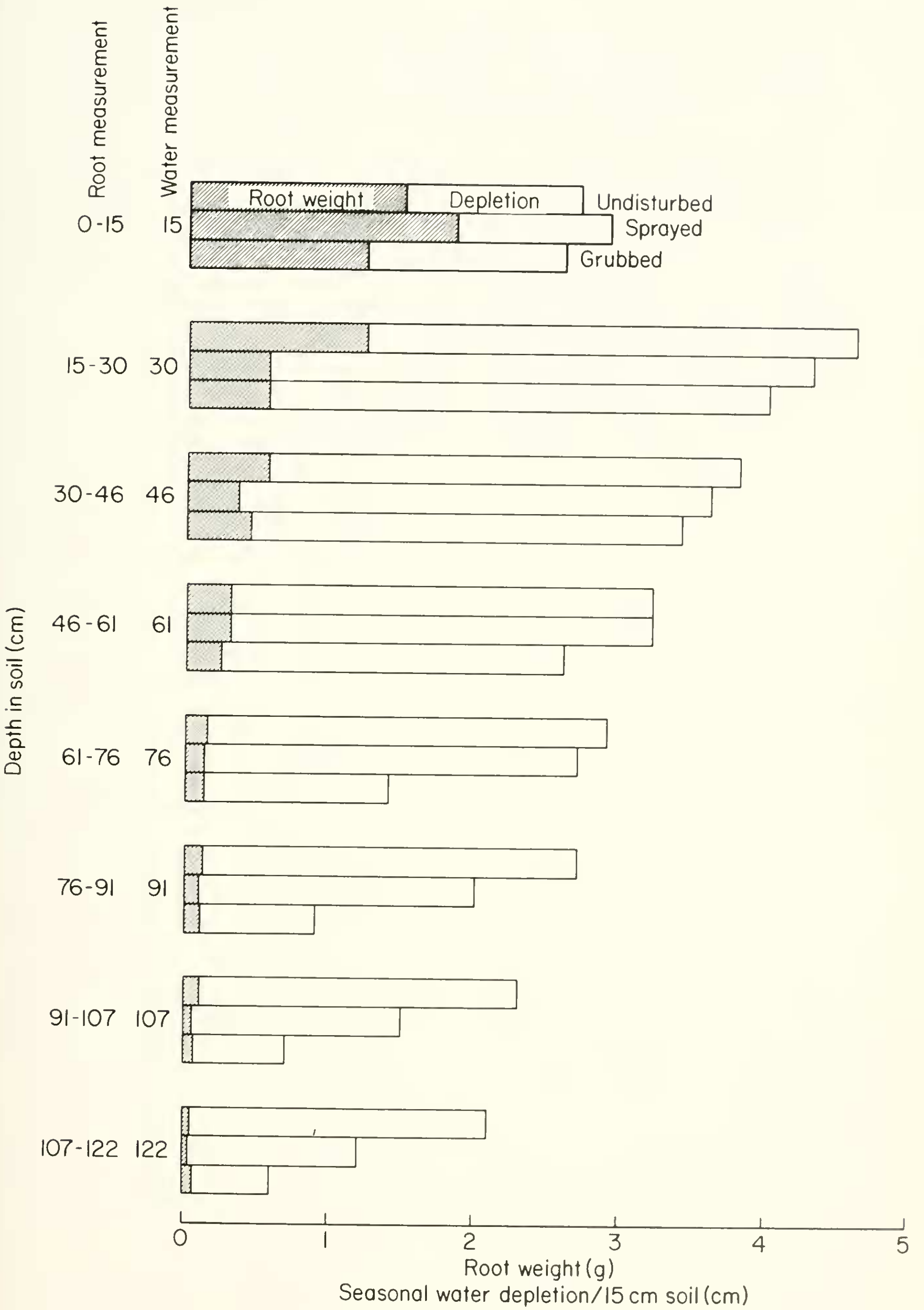

Fig. 4. Seasonal water depletion and weight of roots in soil cores 7.6 cm in diameter and 122 cm long under undisturbed, sprayed, and grubbed sagebrush vegetation.

low 61 cm. Sprayed vegetation, unlike grubbed vegetation, had fully responded to release from sagebrush competition and depletion did not become appreciably less than that of undisturbed vegetation until a 91-cm depth was reached. Reductions in treatment effect through time within soil 60–90 cm deep were described by Hyder and Sneva (1955), Cook and Lewis (1963), and Shown et al. (1972).

The reduction in seasonal water use and in root weight caused by treatments are similar when expressed as a percentage of values for undisturbed vegetation. Seasonal depletion was 33 and 12 percent less for grubbed and sprayed vegetation, respectively, and root weights were 29 and 16 percent smaller on these same treatments. Similar agreement between depletion and root weight did not exist for individual measurement depths (Fig. 4). Thus, root weight measurements do not verify or refute the hypothesis that root development by herbaceous species in the surface 90 cm of soil subsequent to sagebrush removal accounts for increases in moisture use from this zone. Measurement of root length, rather than root weight, probably would have provided a better measure of potential moisture draft because of the differences in morphology of grass and sagebrush roots.

Comparisons of seasonal moisture change and root weight with depth does indicate that deep roots are extremely important in extracting soil water, even though they comprised a small part of root weight in soil cores (Fig. 4). Summer precipitation is usually ineffective in replenishing soil water levels in the sagebrush zone, so that deeper soil becomes an important water reservoir when surface soil dries. A progressive, downward shift of major water use zones in August was especially evident for undisturbed sagebrush vegetation (Fig. 3).

Results of this and other soil water depletion studies indicate that control of big sagebrush with methods that do not destroy all vegetation on lands with an adequate population of herbaceous species has a relatively small effect upon the soil water regime. Changes in the soil water regime can, at most, result in small increases of streamflow. This response will only occur on lands where soils are deeper than 90 cm and soil water recharge exceeds that required to fully wet the soil mantle. The maximum reduction in depletion will usually occur in the treatment year because of productivity increases by herbaceous species in years immediately after treatment. Consequently, justification for big sagebrush control must rest on the benefits derived from shifting site resources to species more desirable than sagebrush from a given land management perspective.

LITERATURE CITED

BROWN, G. R., AND J. F. THILENIUS. 1976. A low-cost machine for separation of roots from soil material. J. Range Manage. 29:506–507.

———. 1977. A tool and method for extracting plant-root-soil cores on remote sites. J. Range Manage. 30:72–74.

COOK, C. W., AND C. E. LEWIS. 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manage. 16:245–250.

GOODWIN, D. L. 1956. Autecological studies of *Artemisia tridentata* Nutt. Unpublished dissertation, Washington State Univ., Pullman. 79 pp.

HULL, A. C., JR., AND G. J. KLOMP. 1974. Yield of crested wheatgrass under four densities of big sagebrush in southern Idaho. U.S. Dept. Agric. Tech. Bull. No. 1483. 38 pp.

HYDER, D. N., AND F. A. SNEVA. 1956. Herbage response to sagebrush spraying. J. Range Manage. 9:34–38.

PIERPOINT, G. 1966. Measuring surface soil moisture with the neutron depth probe and a surface shield. Soil Sci. 101:189–192.

SHOWN, L. M., G. C. LUSBY, AND F. A. BRANSON. 1972. Soil-moisture effects of conversion of sagebrush cover to bunchgrass cover. Water Resour. Bull. 8:1265–1272.

STURGES, D. L. 1977a. Soil moisture response to spraying big sagebrush: A seven-year study and literature interpretation. USDA For. Serv. Res. Pap. RM-188. 12 pp. Rocky Mt. For. and Range Expt. Stn., Fort Collins, Colo.

———. 1977b. Soil water withdrawal and root characteristics of big sagebrush. Am. Midl. Nat. 98:257–274.

STURGES, D. L., AND M. J. TRLICA. 1978. Root weights and carbohydrate reserves of big sagebrush. Ecology 59:1282–1285.

TABLER, R. D. 1964. The root system of *Artemisia tridentata* at 9,500 feet in Wyoming. Ecology 45:633–636.

———. 1968. Soil moisture response to spraying big sagebrush with 2,4-D. J. Range Manage. 21:12–15.